



Cluster Decline and Resilience

The Case of the Wireless Communication Cluster in North Jutland, Denmark

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Cluster decline and resilience

-The case of the wireless communication cluster in North Jutland, Denmark

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Abstract

Most studies on regional clusters focus on identifying factors and processes that make clusters grow. However, sometimes technologies and market conditions suddenly shift, and clusters decline. This paper analyses the process of decline of the wireless communication cluster in Denmark, 1963-2011. Our longitudinal study reveals that technological lock-in and exit of key firms have contributed to impairment of the cluster's resilience in adapting to disruptions. Entrepreneurship has a positive effect on cluster resilience, while multinational companies have contradicting effects by bringing in new resources to the cluster but being quick to withdraw in times of crisis.

Keywords: Regional clusters, cluster decline, resilience, wireless communication industry

JEL codes: R11, R12, O33, L26

1. Introduction

Regional clusters have gained much attention from scholars and practitioners over the last 20 years. One of the aspects investigated intensively in cluster research is emergence and growth of clusters. Recent empirical studies have shown that entrepreneurship is often a key driver to formation of clusters (see, for example, KLEPPER, 2010). In contrast, relatively little is known about how clusters evolve over time and why some clusters decline. Survival of clusters is of great interest for policy makers, as decline will cause turmoil in regional economies. Detailed empirical studies on cluster decline are thus crucial in order to reveal patterns in how clusters decline.

It is commonly observed that disruptions, which often come from sudden changes in the industry, key technologies, and the market, pose threat to clusters. The seminal work by GRABHER (1993) on the decline of the Ruhr district describes how the cluster started to decline after a disruption in demand. He argues that firms were not able to adapt to the disruption because of lock-in. Examples of Silicon Valley and Route 128 also show how disruptions affect clusters. Both clusters went through turbulence in the 1980s: Silicon Valley faced fierce competition from Japanese chipmakers and had to give up the RAM module market, while Route 128 lost its customers as they shifted from minicomputers to workstations and personal computers. Both clusters survived the threats, but in other cases, clusters start to decline after disruptions. Clusters' lack of resilience against disruptions thus appears to be a key issue in explaining cluster decline. WALKER et al. (2004) define resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks" (p. 5). Applied to clusters, resilience can be interpreted as an adaptive capability that allows a cluster to make changes to overcome internal and external disruption and still function with its identity as a cluster within a particular fieldⁱ.

This paper investigates the process of cluster decline and the role of resilience in this process. The conclusions derived in the paper are based on a detailed case study of the wireless communication cluster in North Jutland, Denmark 1963-2011. The cluster emerged in the 1980s and grew quickly during the 1990s, along with the rapid growth of the mobile communications industry; however, the cluster began to decline around 2004. In its history, the cluster experienced three disruption periods. The clusters survived the first technological disruption in the late 1980s. When the second disruption period, with a technological disruption and an economic recession, hit the cluster in the early 2000s, entry of new firms stopped, while exits increased. This process of decline was enhanced in 2009, when the third technological disruption and another economic recession came, and the two largest R&D firms closed down within a few months.

The paper contributes to the literature in the following ways. Firstly, the paper provides a detailed longitudinal study on cluster decline, which is rather scarce in the literature. The rich empirical evidence enhances the current understanding of cluster decline. The data that span the whole history of the cluster allowed the analysis of the decline in light of the development path that the cluster has experienced. Rather than focusing on the recent declining phase, the firm-level dynamics from the very beginning of the formation of the cluster until now are taken into account in analysing the factors that led the cluster to decline. Secondly, a new explanation for cluster decline with attention to disruptions and resilience against the disruptions contributes to refinement of the theoretical discussion on the subject. The paper argues that resilience should be studied in order to understand why and how clusters decline. Firm-level dynamics explain the resilience of the cluster as a whole, which means that individual firms' strategy and action need to be studied to analyse cluster resilience.

The analysis reveals that 'lock-in' was the major force that hampered the resilience of the cluster. Innovation (renewal of technological competence) and new firm formation (including spinoffs) are identified as the factors that increase the cluster's ability to overcome threats, while the presence of multinational corporations (MNCs) is found to have two contradicting effects on resilience. On the one hand, MNCs increase the employment level and bring investments and new knowledge into the cluster, but on the other hand, they are ultimately footloose and will quickly withdraw from the cluster in times of crisis.

Theories of cluster resilience and decline are presented in Section 2 of this paper. Section 3 describes the methodology used here. The case of the wireless communication cluster is described in section 4. The discussion and conclusions follow in sections 5 and 6 respectively.

2. Theories of cluster decline and resilience

2.1. Cluster decline

The cluster literature has focused on the positive effects that lead to clustering, such as the Marshallian externalities, explaining that firms benefit from co-location in a cluster through economies of specialization, economies of labour pooling and localized knowledge spillovers. However, most of these positive factors also have a negative side. When many related firms are co-located, the congestion effects raise prices and wages. Labour pooling increases competition for specific skills and thus raises wages. It is also easier for employees to change jobs within a cluster, which means that companies can lose valuable knowledge to potential competitors. In addition, the localized knowledge spillovers also lead to loss of information that could weaken firms' performance. The attraction of other firms to the cluster

might therefore hamper the incumbent firms' growth (FALCK *et al.*, 2011). SORENSEN and AUDIA (2000) find both a higher start-up rate and a higher exit rate in clusters, thus the churn is higher, which indicates the existence of negative externalities.

'Lock-in' is a frequently mentioned cause of cluster decline. According to GRABHER (1993), lock-in consists of factors that diminish a cluster's ability to recognize and make adjustments to sudden changes in demand. He found that strong inter-firm linkages that emerged in the process of adaptation to a specific economic environment paralyzed the region's adaptability. Grabher identified three kinds of lock-ins. The first is a functional lock-in, which refers to hierarchical inter-firm relationships that hinder suppliers from developing critical functions such as marketing and R&D. Cognitive lock-in means that clustered firms share a common worldview or mindset that makes it hard for them to respond to outside changes. Political lock-in concerns institutional effort to maintain existing industry structures which might damage the development of creativity.

Lock-in draws focus to the internal dynamics of a cluster, but what reveals the rigidity resulting from lock-in and initiates cluster decline are often external shocks that require changes in the cluster. Therefore, to understand cluster decline, it is necessary to look at the cluster's resilience, which explains how clusters adapt to shocks, such as economic recessions, environmental disasters, institutional disruptions, organizational disruptions, market disruptions and technological disruptions. Technological disruptions in particular change the underlying knowledge base for an industry and can easily lead to decline if the cluster firms are not able to move to the new technology (CHRISTENSEN, 1997; DALUM *et al.*, 2005; STORPER and WALKER, 1989) .

2.2. Cluster resilience

MARTIN (2012) identifies three types of resilience: engineering, ecological and adaptive. Engineering resilience is the ability of the system to return to its pre-disruption level. Ecological resilience is the scale of disruption a system can absorb before it breaks down or moves to another stable state. Adaptive resilience is the ability to reorganise in order to minimise the impact of a disruption. Martin also identifies four dimensions of regional resilience: resistance, renewal, recovery, and re-orientation. These dimensions show how regions respond to external disruption. In this paper, cluster resilience is defined as the adaptive capability of a cluster to make changes that allow it to overcome internal and external disturbances and still function with its identity, which is linked to its particular field. The capability consists of the ability to withstand external shocks, the ability to make small and large changes, and the ability to transform itself without losing its identity.

Lock-in and new firm creation

As mentioned above, the case of the Ruhr area shows that lock-in affects the resilience of a cluster negatively in times of crisis (GRABHER, 1993). The Ruhr area faced disruptions stemming from falling demand and rising competition as early as in the 1960s. However, the functional lock-in led to lack of innovation among suppliers, which were suffering from 'dependent supplier syndrome', and the groupthink from the cognitive lock-in made the firms believe that the worrying demand trend was only a short-term disruption. The firms were thus not able to respond in a timely manner to the changes in the environment. Employment in the Ruhr area had decreased by 100,000 jobs in the first half of the 1980s, and the unemployment rate was close to double of that of West Germany overall in 1988.

The Ruhr case also proves that new firms contributed to the eventual reorganization of the industrial district that followed the decline. During the last half of the 1980s, some plants closed down, while some other firms moved headquarters and R&D departments to other regions. Steel firms changed their strategic direction and began to focus more on 'processing of steel', diversifying into plant engineering, environmental technology, mechanical engineering, and electronics. A new industrial complex in environmental technology was formed in Ruhr, comprised mainly of newly established firms from 1982 on. Thus, entrepreneurship was one of the forces that drove the renewal of the old industrial district.

Similarly, SAXENIAN (1990) found that the high rate of new-firm formation in Silicon Valley fostered industrial adaptation in the 1980s, when semiconductor producers were challenged by Japanese competitors. Unlike the established companies in the region, these new firms began to specialise in certain areas of expertise, such as chip design and fabrication processes, and contributed to strengthening the competitiveness of the region as a whole. SIMMIE and MARTIN (2010) argue that the Cambridge high-tech cluster recovered from the early 1990s recession by continuously branching out in sub-clusters based on a strong knowledge platform in advanced mathematics and computing. New firms played an important role in this process.

Among the different types of entrants into clusters, spinoffs are found to be especially important for cluster evolution (BUENSTORF and KLEPPER, 2009; DAHL and SORENSON, 2009). Spinoffs, defined as firms established by entrepreneurs with experience from existing firms in the same industry, tend to locate close to the 'parent' companies and perform better than other entrants, thereby driving the formation of clusters. However, some firms are better training grounds for entrepreneurs and create more spinoffs than others, while some companies never produce a single spinoff (KLEPPER, 2010). If the first

type of company closes down, it reduces cluster resilience by limiting adaptability through entrepreneurship.

Multinational corporations (MNCs)

Resilience concepts often focus solely on internal factors within a certain boundary, but cluster firms have outside links that affect cluster resilience. Sometimes these interactions are positive for the cluster, as when firms are able to receive information, knowledge and resources from the outside. However, they can also be negative, as when multinational companies decide to close down subsidiaries or limit their R&D activities.

MNCs are increasingly basing their knowledge-intensive activities in clusters, “affecting both the nature and intertemporal evolution of local innovative activities” (MUDAMBI and SWIFT, 2012, p.1). The effect of MNCs on cluster resilience depends on their motives for entering and staying in the cluster. Two main motivations for foreign direct investments (FDI) can be identified. The first is the classic ‘technology-exploiting’ motivation, in which a company enters a location where it has technological superiority over local rivals that can be exploited better by FDI than by export (DUNNING, 1979). The second motivation is ‘technology-sourcing’ (DRIFFIELD and LOVE, 2003; FOSFURI and MOTTA, 1999). Firms with this motive enter a market to access proprietary technology, hoping for ‘reverse spillover’ from technology leaders.

Empirical analysis of productivity spillover of FDI in the UK, DRIFFIELD and LOVE (2007) reveals that inward FDI motivated by ‘technology-exploiting’ rationale leads to positive spillover, whereas ‘technology-sourcing’ FDI has no effect. The explanation offered for this is that firms that are ‘technology-exploiting’ have superior technology compared to local firms, while firms with ‘technology-sourcing’ motivations are typically technology laggards. DE PROPRIS and DRIFFIELD (2006) analysed the spillover effect of FDI on domestic firms and foreign-owned firms in clusters. They found that cluster firms – regardless of their origin – gain significantly from FDI compared to non-clustered firms.

Foreign-owned firms, however, are less-committed than indigenous ones. Foreign firms are more likely to restructure, relocate, sell, and close down units in times of economic downturn (GÖRG and STROBL, 2003). The effect of MNCs on cluster resilience is thus a double-edged sword, as these companies bring resources to the cluster, but might also leave quickly.

2.3. Disruptions and resilience in explaining cluster decline

This section attempts to build a framework to explain cluster decline based on the above discussion in the literature, in which it is often found that clusters experience disruptions. The concept of resilience is important for explaining cluster decline, as a cluster's evolution after disruptions depends on its level of resilience. Facing disruptions, clusters with high resilience will be able to reorganise to respond to change and maintain their status, while clusters with low resilience will start to decline.

When a company downsizes or closes down in a resilient cluster, the laid-off employees are often able to get a job in another firm or establish spinoffs in the cluster. Similarly, new firms may enter the cluster, since they can get entire teams of highly-skilled labour. The knowledge and skills are kept in the cluster, and employment seems to be fairly stable against internal and external events. However, when the cluster's resilience is low, shocks may be disastrous. When companies close down, highly skilled employees leave the cluster and get a job in other industries or regions. When the number of firms and employees declines, the knowledge base shrinks. The firms' organizational template is lost, since the knowledge of the firm is more than the sum of the employees' knowledge. Although the knowledge might live on in employees, the exit of firms limits the diffusion of knowledge and leads to a loss of knowledge, interaction, learning through observation, and organizational routines (HOETKER and AGARWAL, 2007).

Cluster resilience is a population-level concept. It is important to remember that a cluster consists of many firms and organizations that have different strategies. The only way the cluster can change is through the actions of individuals, firms and other organisations, all of which may react very differently to the same change. However, the reaction of a cluster as a whole appears to be more than the combined effect of reaction of individual actors because of the interconnections among them. Therefore it is necessary to investigate the actions of different actors in a cluster when studying cluster resilience.

Some factors are influential in cluster resilience. What seems to strengthen cluster resilience is new firm creation, as new entrants contribute to reorganisation of a cluster by branching out into new, promising areas. MNCs can have both positive and negative effects on resilience. MNCs can be the source of new knowledge and financial resources for the cluster, but these firms can also remove resources quickly. Lastly, different types of lock-in make clusters less resilient, as they work against adaptive capability.

3. Methodology

3.1. Data collection

The data on the wireless communication cluster in North Jutland 1963-2011 was collected in the following ways. First of all, the archives from earlier studies on the emergence and development of the

cluster (DAHL *et al.*, 2003; DALUM, 1995) were used to identify cluster firms and the early events of the firms. The list of all firms that were active in the cluster until 2003 had been compiled by DAHL *et al.* (2003) with the founding and exit year (if any), the names of founders and their previous workplaces, and the main events in the history of the firm, such as acquisitions and bankruptcies. Then, new entrants from 2003 onwards were identified by consulting the cluster organization's archive on member companies and searching various online databases for newspaper articles, media reports and corporate information. With the updated list of firms, the founders of the new companies and their former employers were investigated in similar ways, mainly using online corporate databases, corporate websites, online network platforms, and newspaper articles. Each firm has been researched thoroughly for main events including ownership changes and close-downs, mainly using internet and newspaper sources.

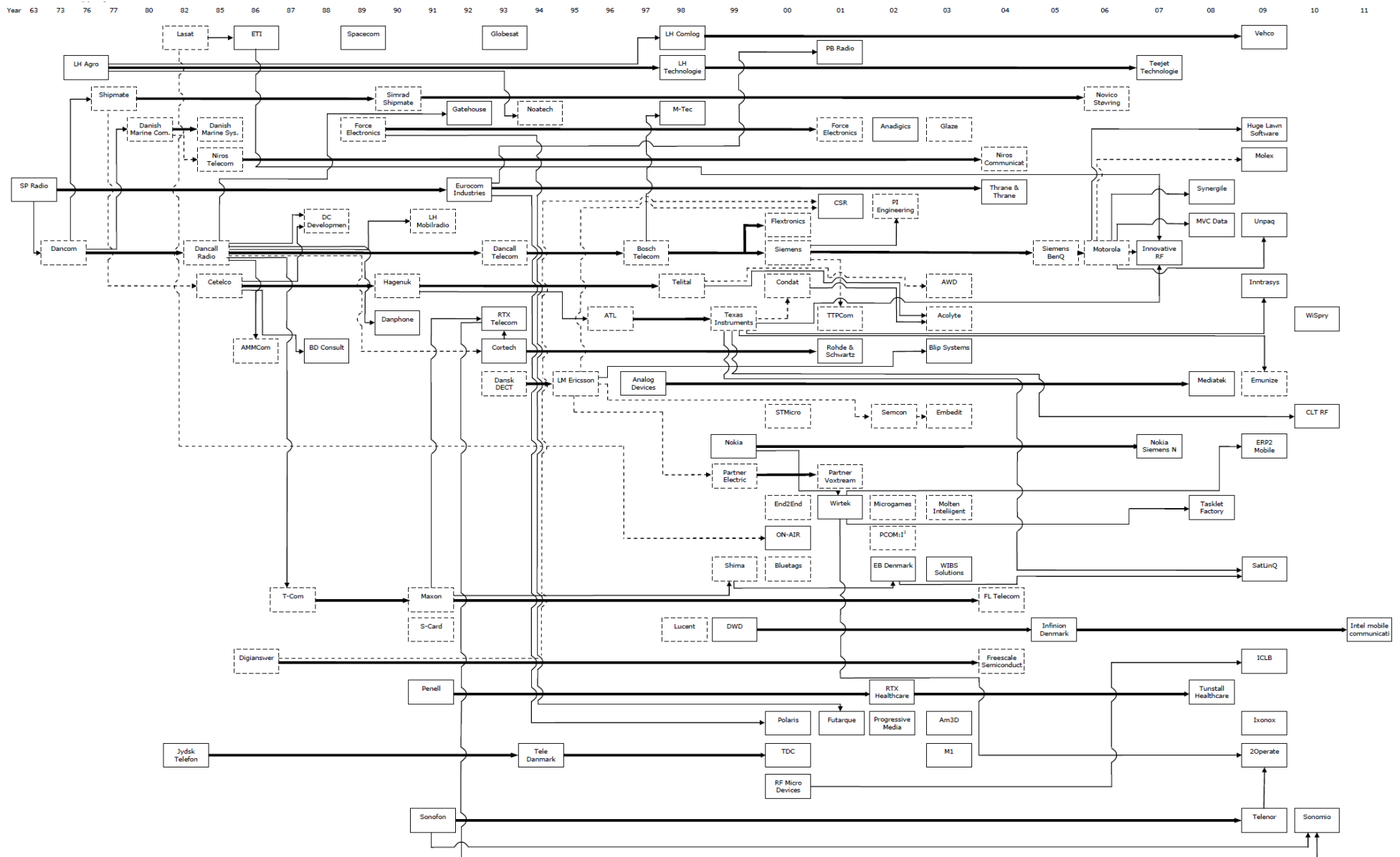
The next step was to collect data on the number of employees of each firm for the last two decades. The early employment data until 2002 came from earlier work on the cluster (DALUM, 1993, 1995, 1998; DALUM *et al.*, 1999; DALUM *et al.*, 2002; PEDERSEN, 2001). The more recent numbers are collected from diverse corporate databases, depending on the time periods in which the firms existed. Since not all firms are covered by those databases, newspaper articles and media reports were used to find the numbers that are missing. After this step, there were still some numbers lacking. These were estimated by taking the average of the numbers before and after the missing period, assuming that the number of employees grew or decreased linearly.

The last part of the data includes a list of former Motorola and Texas Instruments employees who were laid off when the two firms exited the cluster in 2009, and their new workplaces, including the location and each person's new job function. The data for the former Motorola employees came from one employee who kept track of where his colleagues found new jobs. The list of former TI employees was compiled by the authors by searching an online network platform.

3.2. The genealogy of the cluster

The genealogy of the wireless communication cluster from 1963 to 2011 summarizes the history and shows the importance of spinoff activities in the development of the cluster (see figure 1). Fine arrows between firms show that one or more employees from existing firms established spinoff firms. Dotted arrows represent parent spinoffs where the founders or initial management have come from local firms. Bold arrows show change in the original structure of the company, including acquisition by another firm and reconstruction after financial difficulties. Firms with a dotted box have exited the cluster.

Figure 1 The genealogy of the cluster



Source: Updated from the genealogical evolution figure in Dahl et al. (2003, p.20)

4. The wireless communication cluster in North Jutland

The cluster includes firms in the field of maritime communication and navigation, telecom and land-based satellite communications equipment, and mobile and cordless communication. In 2011, it consists of 45 firms, 2300 employees, a university and a cluster association. The cluster has experienced three periods of major external disruptions: 1) from 1988-92, following the shift of the mobile communications standard from the Nordic NMT standard to the European GSM standard; 2) from 2000-3, when the mobile communications standard shifted to a world communications standard, and the telecommunications industry was in turmoil following the 3G spectrum auctions and the dot-com crisis; and 3) from 2007-9, during the financial crisis, the new shift in mobile communications standards, and the introduction of Apple's iPhone and the Android smart phones.

The next sub-section investigates in more detail how the disruptions affected the cluster and how the firms reacted, while the following sub-sections analyse the evolution of the number of firms and employees in the cluster and how the resilience of the cluster changed over time

4.1. Disruptions and resilience of the cluster

The emergence of the cluster (1960-80s)

The history of the wireless communication cluster in North Jutland (named Norcom) started with the success of the leading producer of maritime communication equipment, S.P. Radio. The company, established in Aalborg in 1942, produced consumer electronics until the early 1960s, when the founder decided to produce radio communication equipment for maritime use for small and medium-sized vessels. The company enjoyed huge success by diversifying into this area, as there was almost no competition in the market, and its equipment was technologically more advanced than those of its few competitors. A couple of successful local spinoffs sprang up from S.P. Radio in the 1970s. In 1973, three engineers from S.P. Radio established the first spinoff company, Dancom. It also produced maritime communication equipment, and competed with S.P. Radio in the same markets. A few years later, two engineers from Dancom started Shipmate, which also produced radiophones for maritime use.

In the 1980s, a range of next-generation spinoffs came from Dancom (restructured and renamed Dancall Radio in 1983) and Shipmate. These companies diversified into the related area of personal mobile communication equipment, which was led by the introduction of new technology – the common Nordic standard for mobile telephony (NMT)ⁱⁱ. Inheriting capabilities within maritime radio communication from the parent companies, the spinoffs were well-equipped for this diversification. One example of next-generation spinoff is Cetelco, which was established as a parent spinoff by Shipmate. Cetelco developed

its first NMT phone in 1986, and began to produce mobile phones for several European and East Asian countries. At the end of the 1980s, there were 15 firms in the cluster, and the majority of those were spinoffs.

The first disruption (1988-1992) and the result (1990s)

In the late 1980s, a new generation (2G) began to emerge as European telecommunication operators decided to create a pan-European system (GSM) based on digital technology. This became the first technological disruption that the cluster faced. The use of digital networks enhanced voice clarity and allowed for semi-global roaming. Thus, the cluster firms faced both increased technological complexity and international competition. To overcome this disruption, Dancall and Cetelco formed a joint venture company, DC Development, to develop the basic modules of a GSM phone together with Aalborg University. DC Development succeeded in developing the modules, and its parent companies were among the first to produce a GSM phone. Other firms in the cluster followed other strategies; for example, Maxon decided to continue to make 1G phones, and then moved into 2G later on when the technology had matured slightly.

In the 1990s, more spinoffs were founded based on GSM technologies, producing mobile phones, chips and other components, or supporting technologies. This development, however, was not smooth, since several companies in the cluster faced severe financial and technological problems following the shift from 1G to 2G. Most of the troubled companies and laid-off employees were taken over by other companies in the cluster, and new companies entered it, which shows that the cluster was resilient in this period. For example, financial constraints of the two firms, Dancall and Cetelco, that had pioneered the development of the first GSM phones led to their acquisition by other firms in the early 1990s. Cetelco was acquired by Hagenuk in 1990, and continued to grow afterwards. However, due to unexpectedly high development costs, the company stopped production to focus on R&D, and was later acquired by Telital. Dancall also experienced financial trouble, as their newly developed GSM phone was not competitive because of its high price. Furthermore, the export of NMT phones suffered from the growing GSM phone market and the closing of the markets in the Middle East during the Iraq war. Consequently, Dancall was acquired by Amstrad in 1993.

Despite these financial difficulties, the total employment in the cluster increased constantly from 1992. By the end of the 1990s, the number of firms in the cluster had more than doubled, mainly due to entry by spinoffs. Among the 20 entrants then in the cluster, seven were entrepreneurial spinoffs and six were parent spinoffs of foreign companies such as Analog Devices, Lucent, Infineon, and Nokia. In this period, the ownership structure of the cluster changed significantly, as many MNCs entered the cluster to access the competencies of local development engineers (LORENZEN and MAHNKE, 2002). Some foreign

firms like Maxon, Bosch Telecom, Telital and Texas Instruments entered the cluster by acquiring already-existing firms. By the late 1990s, GSM had become a de facto global standard, and sales boomed.

The second period of disruptions (2000-2003)
–economic recession and technological disruption

The cluster experienced an external shock in the early 2000s when the telecommunication sector was hit by stagnating sales after the burst of the dot-com bubble. After this economic recession, the MNCs in the cluster changed their strategies, and either collected R&D units in the home country, or reduced R&D expenses in the subsidiaries. Consequently, many of the MNCs downsized and sacked local engineers. Some existing and new firms were able to absorb the released work force from the MNCs, and some engineers even established their own companies. When Cetelco (then owned by Telital) closed down in 2002, some employees joined parent spinoffs newly established by two other foreign companies, Advanced Wireless Design and Acolyte, in 2003. Nokia decided to move its R&D unit to Copenhagen in 2001, and former employees from this unit established Wirtek. Some local firms were also affected by this crisis and closed down. Despite the downsizing and exits, the number of companies grew, as there were many new companies entering the cluster. The number of employees decreased slightly from 2000 to 2002, but this recovered and even reached a record high in 2003.

In a report from 2002 on the future of the wider ICT sector in the region, some of the managers for MNCs complained about the lack of local decision-making power in deciding R&D strategies (DALUM and PEDERSEN, 2002). Others feared that distance to end-users and lack of knowledge related to production might become a problem. Many of the MNC subsidiaries were dependent on single customers or on internal sales. The shift from 2G to 3G, the technological disruption, also posed a threat to the cluster. The standardization process for 3G had become global planning to create a global standard, bringing about intense global competition. The complexity of the technologies and the pressure on time-to-market had also increased. The firms in the cluster had various strategies. Some firms were initially active in 3G research (e.g. L.M. Ericsson, which closed down the unit in the cluster in 2003), and others decided to adopt wait-and-see approach to the development. Some firms tried to cooperate with others in developing the new technologies, but failed (DALUM *et al.*, 2005). As a result, the cluster was not very active in the new technology, which reduced its resilience.

The impact of the second wave of disruptions started to show in 2004, as many firms closed down or downsized, while there were no new entries. This implies that the resilience has been reduced and the cluster could not reorganize itself after the shock. One of the big companies, Flextronics, closed down with 500 employees in 2004. The headquarters in Singapore decided to move the production to lower-cost locations. The close-down was considered a tragic event, but the overall R&D employment was stable in the cluster, as the main layoffs were of low-skilled production workers.

The third period of disruption (2007-2009) **–technological disruption and economic recession**

The introduction of the iPhone and Android-based phones in 2007 resulted in a significantly decreased demand for 2G technologies, while the financial crisis decreased the general demand. These technological and economic disruptions posed serious threats to the cluster. As a result, two central players in the cluster, Motorola and Texas Instruments (TI), ceased their activities in the cluster in 2009. Motorola entered the cluster by acquiring BenQ in 2006, but soon after their entry, the company faced unfavourable conditions in the market. The rapid growth in demand for smart phones and the subsequent rise of new competitors made Motorola's market share drop from 14.3 per cent in 2007 to 8.7 per cent in 2008 and 4.8 per cent in 2009. Motorola's Aalborg division had focused on development of new mobile telephones and production planning until its headquarters decided to switch to Google's Android operating system, reduced the number of newly developed models, and eventually closed its European mobile-phone divisions. TI acquired local ATL Research in 1999 and Condat in 2002. TI suffered from focusing on chipsets for 2G phones instead of 3G phones, and ended up closing most of its European divisions. Motorola and TI had to lay off 275 and 75 employees respectively, consisting mainly of highly skilled R&D engineers. Unlike former instances in which MNCs had laid off many engineers, this time the cluster could not take in all the released talent. This resulted in workforce migration to other regions in Denmark and to other industries. It seems that the cluster was not able to adapt to this major crisis.

4.2. Overview of the cluster in decline

The effects of the disruptions are also present in the data on employment and number of firms. Figure 2 shows the change in the population and the number of entries and exits. The number of firms had increased steadily until 2003, as there were very few exits before then, and plenty of entries. Then, after the second disruption, between 2004 and 2006, the cluster started to decline; there was no entry at all, while firms continued to exit. In 2008, the number of entries equalled that of exits, because entry numbers started to grow. In 2009, entries peaked, as 10 new firms were established. The majority of these were founded by former Motorola and TI employees. Likely survival of these entrants and their influence on the cluster, however, are questionable. Among eight spinoffs, four have founders with a regular job other than the start-up; these four founders are necessity-driven entrepreneurs, who founded consulting firms while they were between jobs. Moreover, the majority of the new firms have only one or two employees, usually the founders themselves, and most of them do not show employment growth.

Figure 3 shows the change in the number of employees in the cluster. The declining trend is apparent from 2004. Following the second disruption, total employment decreased slightly from 2000 to 2002, but increased again in 2003. From 2003, the number decreased drastically until 2005, as many firms

downsized and exited in this period. Except for an increase of 316 in 2006, the number of people employed continued to decline until 2010, when the number increased by merely 24.

Figure 2 Total population and entry and exit of firms in the cluster

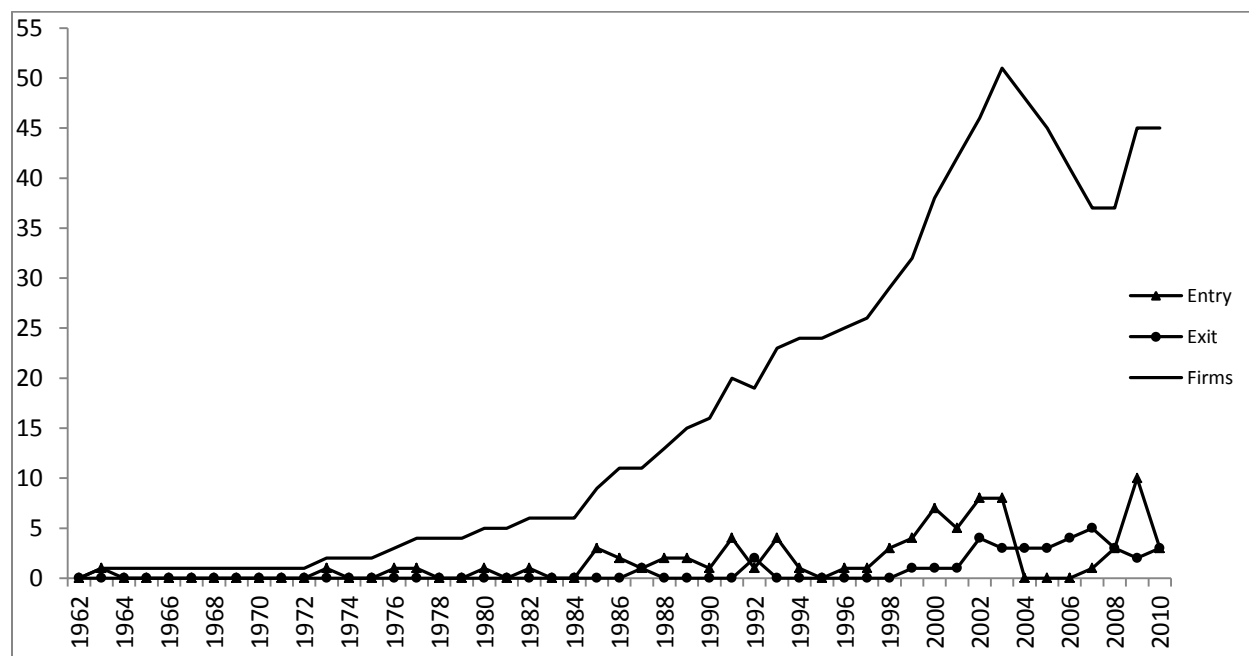
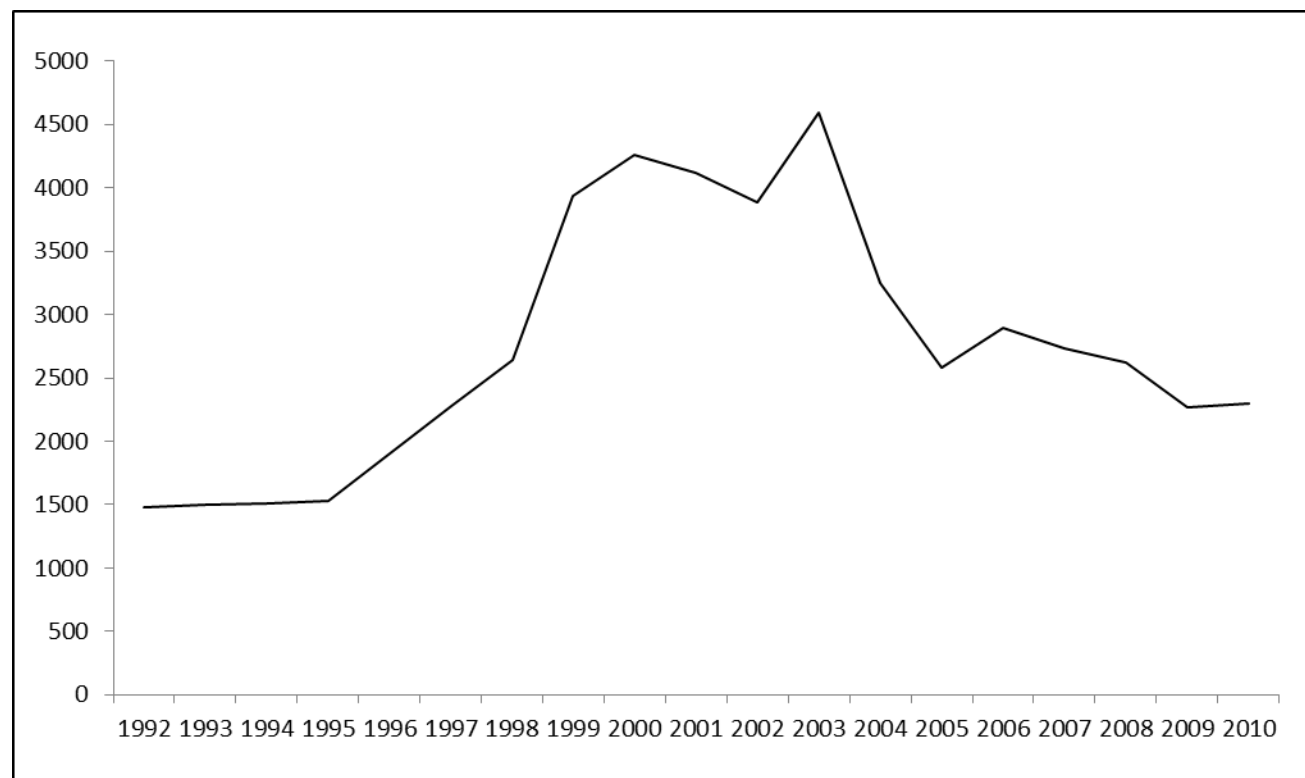


Figure 3 Employment in the cluster



4.3. What changed resilience of the cluster over the years?

Table 1 shows the three disruptions that the cluster faced over time, the dynamics within the industry and cluster at the time of disruptions, the impact of the disruptions, and the level of resilience observed after the disruptions.

Table 1 Major disruptions in the cluster and resilience after each disruption

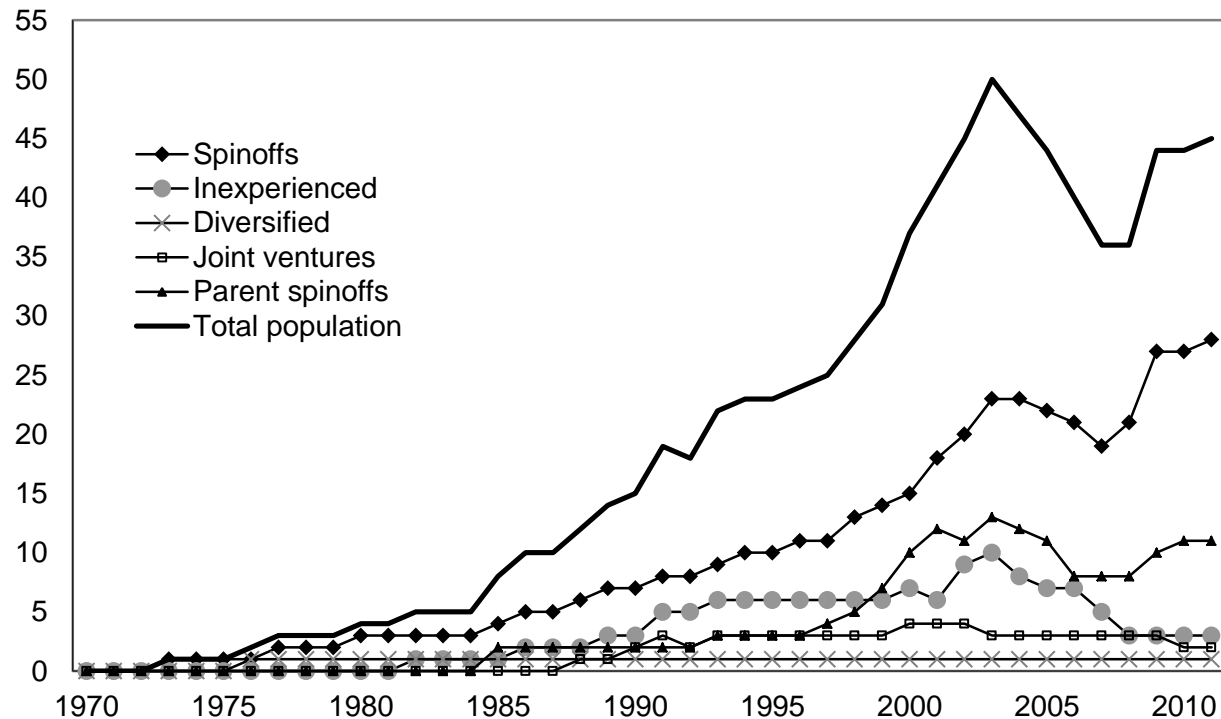
	1988-1992	2000-2003	2007-2009
External disruptions/Threats	<u>Technological disruption</u> <ul style="list-style-type: none"> New standard: 1G (NMT) to 2G (GSM) <ul style="list-style-type: none"> From analogue to digital From Nordic to European Increasing complexity 	<u>Technological disruption</u> <ul style="list-style-type: none"> New standard: 2G (GSM) to 3G (WCDMA/UTMS) <ul style="list-style-type: none"> From European to world wide Increasing complexity Tele service providers and 3G spectrum auctions <u>Economic recession</u> <ul style="list-style-type: none"> Dot-com crisis 	<u>Technological disruption</u> <ul style="list-style-type: none"> New standard: 3G (WCDMA/UTMS) to 4G (LTE) <ul style="list-style-type: none"> Importance of data transmission Introduction of smartphones <ul style="list-style-type: none"> Convergence with computer industry <u>Economic recession</u> <ul style="list-style-type: none"> Financial crisis
Industry dynamics - Demand - Competition - Structure - Technology	<ul style="list-style-type: none"> Larger market spanning the whole Europe Increasing demand for mobile phones Increasing competition Entry by large electronic firms Large scale production Intense technology development Shorter product life cycle 	<ul style="list-style-type: none"> Larger market spanning the whole world Increasing demand Mega competition Alliance between incumbents (e.g. Sony Ericsson) Entry of MNCs from other industries Large scale production Intense technology development Shorter product life cycle Increasing modularisation 	<ul style="list-style-type: none"> New entry : Apple, Google, and Microsoft New operating systems Increasing importance of software products New path in technology development Decline of old incumbents such as Nokia, Motorola, and Sony Emergence of new leaders: e.g. Apple, Samsung, HTC Emergence of new markets: e.g. China, India
Cluster dynamics - Structure - Strategies - Policy	<ul style="list-style-type: none"> Around 15 firms in the cluster Joint venture by Dancall and Cetelco to develop basic 2G technologies. Some other firms continued with 1G phones (e.g. Maxon) Science park NOVI providing entrepreneurial environment to firms Collaboration with Aalborg University and National Telecom Agency 	<ul style="list-style-type: none"> Around 45 firms and 4000 employees in the cluster Increasing number of MNCs in the cluster Specialisation in different components of mobile phones CTIF established at Aalborg University to focus on 4G technologies Seedbed firms exited Fragmented strategies of firms led to lack of 3G competences in the cluster <ul style="list-style-type: none"> Attempt on collaboration on 3G failed Maxon did not move into 3G Ericsson with 3G competence closed down Siemens started offshore outsourcing 	<ul style="list-style-type: none"> Around 40 firms and 2200 employees in the cluster Increasing number of software firms MNCs in crisis Exit of some major firms Diversification among firms Aalborg University focusing on 4G technologies Entry by spinoffs from exiting firms
Result - Resilience - Evolution	<ul style="list-style-type: none"> Increasing number of firms Troubled firms acquired by MNCs Laid-off employees were hired by other firms in the cluster. Resilience was high and the cluster was still in the growing phase 	<ul style="list-style-type: none"> Number of firms and employees started to decrease in 2004 No entry between 2004 and 2006 Resilience was lower than before and the cluster showed signs of decline 	<ul style="list-style-type: none"> Decrease in the number of employees seems to be stabilized while the number of firms increased with new spinoffs from exiting firms Resilience in question <ul style="list-style-type: none"> Firms that generated many spinoffs closed down Survival of new firms is also in doubt Continued decline or possible transition

The most important factor that changed among the three disruptions was the presence of relevant technological competence at the time of transition from one generation of system to another. During the first transition, two firms in the cluster formed a joint venture in order to develop the basic technologies ahead of other competitors elsewhere. The joint venture company succeeded, and the two parent companies, Dancall and Cetelco, were among the first in the world to produce GSM phones. The technological competence broadened as some companies founded a joint venture to focus on cordless phones while others went into the field of Bluetooth standard. Chipset companies like Texas Instruments and Infineon entered the cluster. This broadening of the market and knowledge base must have increased the resilience.

However, when 3G emerged, the development of basic technologies did not take place in the cluster to the same degree as with previous standards. Collaboration efforts initiated by some firms did not succeed, and one company involved in 3G technologies left the cluster. Furthermore, MNCs decided that R&D in 3G technologies should take place elsewhere. When TI acquired Condat in 2002, the company simply closed the 3G technology division. The 3G technology, which became a major disruption, was vastly more complex than 2G and required huge investments in R&D that only large companies could afford. Consequently, the technological competencies within 3G were mainly developed in other parts of the world where the development costs are lower (e.g. Asia). This functional lock-in was initially not a problem, because 3G had a slow start and initially seemed unsuccessful, while 2G products still sold well. A few years later, smart phones boosted 3G sales. Facing this disruption, the lack of 3G competencies became a major problem, and central companies ceased activities in the cluster.

Another factor that might have affected resilience after the second disruption is the exit of firms that had created many spinoffs. Looking at the change in the population of firms by entry type (see figure 4), it can be seen that entrepreneurial spinoffs largely account for the development of the cluster over the whole time period. The spinoff process was especially important in the emergent phase, when offspring from S.P. Radio diversified into mobile telecommunication.

Figure 4 Firm population by entry type



These companies became seedbeds for many spinoffs later on, and were crucial for further development of the cluster. Cetelco had five spinoffs before it exited in 2002. One of its spinoffs, ATL Research (later acquired by Texas Instruments and exited in 2009), also became a seedbed for new firms, as a total of six spinoffs came from this company. In 2003, L.M. Ericsson, which was parent to four firms, ceased its activities in the cluster. This spinoff history confirms that some firms function as training grounds for entrepreneurs who gain relevant capabilities and routines from the parent companies. The exit of these firms reduces cluster resilience, possibly affecting the level and quality of entrepreneurship in the cluster in the future. This might explain the low level of entry from 2004-10, with the exception of 2009.

The next factor that changed was the concentration of MNCs in the cluster. After the first disruption, some local companies were acquired by foreign firms due to financial problems. Moreover, more MNCs entered the cluster in the 1990s, as they were attracted to its competence level. However, the high concentration of MNCs was a weakness during the times of crisis. Many subsidiaries did not have much influence on strategic decisions made by the MNCs' headquarters. When the mobile telecommunication sector was in crisis in the early 2000s, and the financial crisis hit economies worldwide in 2008, many of these MNCs relocated their development activities to bigger R&D centres. Consequently, some firms closed down in North Jutland.

5. Discussion

This case shows the importance of resilience to understanding cluster decline. This cluster faced several disruptions, and was able to adapt to the first, but declined shortly after the second. Clusters often face challenges originating from technological discontinuity and changes in demand, and those that have survived such disruptions, such as Silicon Valley and the Cambridge high-tech cluster, seem to have had strong adaptive capabilities. What is also interesting in the Norcom story is that this adaptive capability can change over time, and that a once-resilient cluster can decline if some factors diminish its ability to renew itself.

The major force that affected Norcom's resilience was lock-in. The three types of lock-in identified by GRABHER (1993) are also observed in this case. The fact that the firms were not able to develop the newly dominant technologies in the industry implies that there was a functional lock-in. Cognitive lock-in among cluster firms perhaps brought about the functional lock-in, as they focused on further development of the already-existing technological competencies in 2G instead of being active in developing new technologies. Political lock-in could be found in the operations of subsidiaries of the MNCs, where the R&D divisions in different locations had to compete against each other for headquarters' choice of new products. Sometimes, the new initiatives of local employees were turned down because they did not fit with the headquarters' overall strategy. What happened in the cluster is also in line with the argument by MARTIN and SUNLEY (2006) that processes and configurations built up in the phase of 'positive' lock-in – in this case, the phase when GSM technologies flourished and created positive externalities – become a source of increasing inflexibility and rigidity.

However, it seems that lock-in is only part of the explanation for the lowered resilience in the cluster. What is also critical to resilience is new-firm creation. When external shocks hit the cluster, firms close down. One way for a cluster to reorganize itself and recover is entrepreneurship. This is proven in our case when the cluster experienced the first crisis in the late 1980s. During this crisis, when firms started to exit, new organizations entered the cluster by either acquiring troubled firms or establishing new entities engaging laid-off employees. Silicon Valley, the Cambridge high-tech cluster, and the Ruhr area all demonstrate the importance of new firms to a cluster's ability to reorganise when facing disruptions.

However, when new-firm formation slows down or stops, as in the case of the cluster in North Jutland between 2004 and 2006, the cluster cannot recover from the continuous firm exit and therefore becomes vulnerable. A decrease in new-firm formation is also observed in the Cambridge cluster in its declining phase around 2005-6 (STAM and GARNSEY, 2009). As with the wireless cluster in North Jutland, the decrease in new-firm formation was more dramatic than the increase in the number of exits, fuelling the decline in the cluster. As establishment of new firms creates variation, it is important to the evolution of a cluster.

In addition, the strong presence of MNCs in the cluster also influenced resilience, yet with some contradictory effects in different time periods. When the cluster was in a growing phase, with strong competence in GSM systems, many MNCs entered the cluster to get access to its highly skilled labour. This confirms that MNCs to an increasing degree enter new locations with the purpose of 'technology-sourcing' (FOSFURI and MOTTA, 1999). After the first disruption in the early 1990s, MNCs did in fact save the leading cluster firms that had severe financial troubles by acquiring them. In this way, the technological competencies that otherwise were in danger of being dissolved into other industries or regions were able to stay within the cluster. The MNCs also provided access to new markets, financial resources and knowledge. Entry of MNCs therefore had a positive effect on cluster resilience in this period. However, when the second disruption came about ten years later, MNCs' presence proved vulnerability. MNCs were largely reactive to changes in the industry, as they readily downsized or simply exited the cluster during the crises, proving that they are much more 'footloose' than local firms (GÖRG and STROBL, 2003). This 'footloose' characteristic needs to be understood in relation to the functions that the subsidiaries had in the cluster. The majority of these organizations were R&D units, which might have increased the reactivity of these firms, as relocation of R&D units is less costly than that of production sites. The MNCs' decision to withdraw from a location also depended on the overall performance of the company. For example, Motorola suffered from a decrease in its market share in the mobile phone market, which directly influenced the company's decision to exit the cluster. To sum up, the presence of MNCs in the cluster, which was generally considered to be positive as they saved some local firms from bankruptcy, clearly weakened its resilience against external shocks.

Although discussion on cluster decline focuses on the negative, this decline can also have positive effects on the regional economy. Sometimes firm exits induce positive development in other industries. BUENSTORF and FORNAHL (2009) found that the exit of one large firm, Intershop, released a wave of creative employees and diffused knowledge throughout the region. Many spinoffs were established by employees from this exiting firm, and a cluster was created as a result. The region of North Jutland might experience the same effect. More than 70 per cent of former Motorola and TI employees have found new jobs outside the cluster since the firm exited in 2009. Of the 71 per cent of employees who stayed within the region, about 17 per cent were absorbed into the related ICT industry in the region, whereas 27 per cent went into other industries. Considering that most of the employees were R&D engineers, this means that these industries acquired strong technological competencies from firm exit. The same pattern is found in spinoff activities by the former employees of Motorola and TI, as many firms were founded by them in ICT and related industries. While it is too early to analyse the effect, the influx of specialised knowledge from this cluster to other industries might be able to strengthen them in the long run. However, the positive effects of cluster decline depend on whether or not the decline is orderly. If the decline is too chaotic, the former cluster employees might not get a chance for smooth transition from one job to

another. This may result in a situation in which they are unable to get jobs at all, or ones in which their competencies are relevant, or in them having to leave the region, thus depressing the local economy.

6. Conclusions

Regional clusters are constantly exposed to external disruptions from changes in the industry and the market. A cluster's ability to adapt to these changes – resilience – determines the evolution of the cluster after such disruptions. This paper analyses the process of cluster decline, which has been a rather neglected subject in cluster research, with the focus on the role of resilience. An in-depth case study on a wireless communication cluster shows that resilience is a useful concept in understanding how and why a well-functioning cluster turns into a declining cluster following some external disruption. The longitudinal study on the cluster examined here enhances the understanding of the factors that influence its development over time.

What can be learned from this case is as follows. When the technological competencies in a cluster cannot keep up with the technological development in an industry, the cluster will be less resilient against disruptions. Therefore, continuous innovation activities at the firm level are crucial to a cluster's resilience. As the three kinds of lock-in seem to hinder innovation activities, clusters should be alert to the emergence of lock-in right from the initial growth stage. Having firms that are rooted in the region is also important to cluster resilience. Clusters with many MNCs prove to be vulnerable to shocks, as MNCs tend to lack commitment to companies and regions. They might also not be as embedded in a region as local firms, which might also hinder collective efforts to overcome crises. Lastly, new-firm creation also strengthens a cluster's ability to overcome threats. Entry of firms compensates for firms' closure following external disruptions. This also increases heterogeneity of knowledge, which makes a cluster more adaptive to change.

Some policy implications can be inferred from the above findings. The fact that a well-functioning and growing cluster can turn into a declining cluster following an external shock tells us that maintaining the status of existing clusters is as important as fostering new ones. To maintain momentum, collaboration between different actors (e.g. public organisations and universities) and cluster firms with the clear goal of renewing technological competencies should be encouraged. Attracting MNCs to a cluster should also be done in a careful manner, as it does not always have a positive effect on cluster evolution.

The findings in this paper point to some relevant future research areas. Firstly, studies on evolution of other wireless communication clusters within the same period of time will reveal more location-specific factors that may affect the evolution of clusters. Secondly, how the resilience of a regional economy is

related to that of a cluster is an area of study that needs more attention, as this has policy implications for both regional economies and clusters.

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ⁱ Clusters are often defined as “geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions in a particular field, linked by commonalities and complementarities (PORTER, 1998, p.199).” This definition is, however, imprecise in delimiting the boundaries of the cluster concerning how the companies are interconnected and how the commonalities and complementarities should be perceived (MARTIN and SUNLEY, 2003). The firms in a cluster must be coherent with activities within a limited part of an industry, and draw on a common pool of labour with knowledge and skills from the same technological knowledge base.

ⁱⁱ The evolution of mobile communication technologies can be explained well by technological life-cycles (DALUM *et al.*, 2005). Different generations of mobile communication technology (1G, 2G, 3G, and 4G) have life-cycles of their own. Within each generation, different systems were developed in different parts of the world (e.g. Nordic countries, central Europe, the U.S., and Asia), and competed with each other. The first-generation technology system (1G) was represented by analogue mobile systems. In 1981, the Nordic mobile telephony operators launched the first cross-national public mobile telephony system, called NMT.